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FOR: SYSTEM FOR REDUCING NOISE IN THE REPRODUCTION OF

RECORDED SOUND SIGNALS

BACKGROUND OF THE INVENTION

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The present invention relates to the processing of electrical signals in connection

with the recording and reproduction of sound, and in particular to the reproduction and

the rerecording and playback of previously recorded sound signals.

10   The applicant is co-patentee of U.S. Patents 4,155,041; 4,151,471 and 4,259,742

and is sole patentee of U.S. Patent 4,322,641. These patents, which are incorporated

herein by reference, are all concerned with the reduction of extraneous noises in the

reproduction of analog sound recordings. These patents disclose three distinctly different

and complementary systems for eliminating or reducing noises in the playback of old

15   cylinder and disc records. The first of these systems eliminates noises in the reproduction

of monophonic disc or cylinder records by virtue of a switching process that selects

reproduction from the momentarily quieter groove wall or from an equal mixture of the

two, requiring that the recording be reproduced with two-track, stereophonic equipment.

The second of these systems eliminates or greatly reduces the amplitude of noise transients

20   that remain after the switching process. The third system reduces the high frequency

"hiss" that is not susceptible to reduction by the first and second systems. The second and

third systems are applicable to both monophonic and stereophonic recordings.

The present invention provides new and improved means by which each of these three systems, individually and in combination, provides superior results in the reduction of noises and achieves major reductions in the artifacts which occasionally limited the versatility of the previous devices.

5   As used herein, the term "input signal" refers to the electrical signal, consisting of generally continuous and transient signals, bearing the audio information intended to be heard by the listener or receiver, plus noise signal. The term "noise signal" refers to the unwanted signals, both continuous and transient, which may be contained in the input signal. The terms "total signal", "signal plus noise" and "program plus noise" are

10   employed, depending on the context, synonymously with "input signal." "Program content" or "music signal" refer to the input signal less noise signal.

SUMMARY OF THE INVENTION

The first of the three signal processors or systems, termed the Switcher, takes advantage of the circumstance that imperfections in a recording such as particulate matter

15   in the record material, defects in manufacture, damage, dirt, wear, mildew, etc., which may introduce transient noises into the reproduction of the recording, are not usually identical on opposite sides of the record groove, whereas, in the case of monophonic phonograph recordings, the signals recorded on each side wall of the record groove normally are identical for all practical purposes. The prior invention, disclosed in

20   aforementioned U.S. Patent 4,259,742, reduces transient noises in the reproduction of a monophonic disc or cylinder recording by means of a three-way switching process between either of the groove's side walls or their average obtained by mixing equally the

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signal on the groove's two side walls. Signals were transmitted simultaneously over each

of two channels with a normally open, fast acting switch in each channel. The switch in

the channel with the least signal plus noise was closed to transmit only the signal from that

channel to the output. When the difference between signal plus noise on both channels

5   was below a predetermined threshold value, both switches remained open and the signals

on both channels reached the output through respective resistors with a third, voltage

dividing resistor. This system was not effective in suppressing noise components of

opposite polarity and non-matching amplitude. The present invention addresses this

problem by simultaneously closing both switches, thereby delivering the average of the

10   total signal on both channels to be conducted to the output.

The second of these three processors detects noise transients and in response

thereto institutes a "blanking" action that limits both positive and negative pulsations of a

transient so that they do not exceed a threshold value established relative to the

momentary peak value of the signal in the vicinity of the transient. However, in some

15   cases, in program material with very steep transients, such as commonly found in

recordings of guitar, harpsichord, pizzicato strings and an occasional strongly attacked

vocal note, the Blanker sometimes produced audible artifacts. It also had some trouble in

distinguishing drum transients from noise transients, and in suppressing low level noise

transients in low signal level areas. The Blanker of the present invention remedies these

20   problems through the use of two fast acting switches, one of which interrupts only high

frequency components of the noise transient and the other interrupting low frequency

components.

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The third system, a "Continuous Noise Suppressor", reduces noise of a continuous nature, usually referred to as "hiss" or, roughly, as "white noise", by means of an electronic circuit wherein the upper limit of the band width of the signal is automatically and continually adjusted in accordance with the relationship of (1) the peak amplitude of

5   the rate of change of the signal with respect to time (i.e. the second derivative of the signal) to (2) the instantaneous amplitude of the signal within a selected frequency band. The Continuous Noise Suppressor disclosed herein has a more effective treble attenuation characteristic with a lower minimum cutoff frequency and a more rapid response to the changing dynamics of a recording, thus further reducing to the acute listener audibility of

10   the continual modications of the cutoff frequency.

Brief Description of Drawings

Figure 1 is a schematic and block diagram representation of the switching system;

Figure 2 is a schematic diagram of the control circuit shown in block form in Figure 1;

15   Figure 3 is a schematic diagram of an alternate embodiment of the control circuit; and

Figures 4 and 5 are schematic diagrams of the Blanker and Continuous Noise Suppressor, respectively.

DESCRIPTION OF THE PREFERRED EMBODIMENT

20   The three systems or processing stages for removing noises from sound signals emanating from such sources as sound recordings, radio broadcasts and the like, may be employed individually or in combination, as dictated by the requirements of the job at

hand. The first disclosed system, the Switcher, two signals which are substantially identical in program content, but which may differ in total signal amplitude due to differing noise content, are received simultaneously on respective channels and appropriate electronic circuitry compares to two input (total) signals and transmits to the recording or

5 reproducing apparatus either: 1. an equal mixture (average) of the two input signals, or 2 the input signal on one of the channels. When that input signal has an amplitude which is lower than the average of the amplitudes of the two input signals by more than a predetermined threshhold amount.

The Switcher

10 Referring now to Figure 1, there is illustrated a system which includes two input channels designated as Channel 1 and Channel 2. For the purposes of this description Channel 1 and 2 are presumed to be the two channels of a stereophonic playback system, although these channels can be the output of any device that is transmitting two signals that are identical in their program component but differ in their noise content. These two

15 channels are connected to the signal sources such that the instantaneous voltage of the program component in each is of the same polarity.

The signals on Channel 1 and Channel 2 are applied to amplifiers 9 and 11 respectively. Associated with amplifier 9 are the fixed resistor 65 and the adjustable resistor 67. These two resistors govern the amount of negative feedback applied to

20 amplifier 9, the gain of the amplifier being adjustable in accordance with the setting of adjustable resistor 67. The values of the two resistors can be chosen so that, when adjustable resistor 67 is set at its center point, the gain of amplifier 9 equals that of

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amplifier 11, thus making it possible to adjust the gain of amplifier 9 over a considerable

range of values both above and below the gain of amplifier 11, so that a considerable

imbalance between the levels of the program component of the input signals (i.e. signal

less noise) of Channels 1 and 2 can readily be compensated for. For the sale of simplicity,

5   the signals being applied to Channels 1 and 2 will be assumed to be equal. However, it

should be understood that signals of unequal magnitude can be accommodated by virtue of

the adjustable gain of amplifier 9.

For optimum operation of the Switcher it is necessary to adjust the program

component signal levels of the outputs of amplifiers 9 and 11 to equality with phase

10   accuracy, which is achieved by providing amplifier 11 with a unity-gain, polarity-reversing

switch (12) and then auditing the output of the Switcher with the switching action turned

off. The gain of amplifier 9 is then adjusted with adjustable resistor (potentiometer) 67 for

maximum cancellation of the program component i.e. minimum "music" signal via

listening. This also allows one to audition noise components independently of the

15   program component. The polarity reversing switch is to be switched back to the non-

reversing position after the potentiometer adjusting procedure is concluded. The signals

applied to Channels 1 and 2 would be of the same polarity when they are the output

channels of a standard, two-channel, stereophonic record-playback system playing a

lateral-cut monophonic recording. When reproducing a vertical-cut disc or cylinder with

20   the same stereophonic record-playing system, the signals applied to Channel 1 would be of

opposite polarity to those applied to Channel 2 and, in that case, the inverse of the above

procedure would be employed.

The output terminal 13 of amplifier 9 is connected to the input 33 of low frequency attenuator 53 and also to input 49 of low frequency restorer 25. Similarly, the output 15 of amplifier 11 is connected to the input terminal 35 of low frequency attenuator 55 and to input terminal 51 of low frequency restorer 25. The output terminal 37 of low frequency

5   attenuator 53 is connected to terminal 57 of a normally open, fast-acting switch 27 and also to input 21 of the control unit 19. The output terminal 39 of low frequency attenuator 55, identical to attenuator 53, is connected to terminal 59 of normally open, fast-acting switch 29 and also to input 23 of control unit 19. The output 61 of switch 27 is connected through resistor 60 to the input 43 of summer 31; output 63 of switch 29 is

10   connected through resistor 62, to input 43 of summer 31. The output 41 of low frequency restorer 25 is connected to input 47 of summer 31. The output 39 of summer 31, which is the output of the Switcher, should be identical to the signal that is presented in Channel 1 and/or Channel 2 less the detected audible noise transients which the switching process has eliminated.

15   Resistor 101 is in parallel with switch 27 and resistor 102 is in parallel with switch 29. These two resistors are of equal value and, when switches 27 and 29 are both open, provide equal conductive paths to summer 31 from the outputs of both low frequency attentuators 53 and 55. These attenuators serve to eliminate from the switching process low frequency disturbances such as rumble, hum and thumps which either exist on a

20   recording or may be introduced in the playback process. These attenuators also serve to protect the control unit from misoperations which could be caused if these disturbances were not filtered out. The integrity of phase relations within the program content of the

signal is preserved by designing the circuit of the low frequency restorer 25 to be an inverse complement of the low frequency attenuator circuits 53 and 55 such that the sum of the signals at 37 and 41 is identical in its frequency and phase relationships with that at output 13 of amplifier 9.

5   A first embodiment of control circuit 19 is shown in Figure 2, wherein inputs 201 and 203 correspond to control circuit inputs 21 and 23, respectively, of Figure 1. The inputs 201 and 203 are connected, respectively, to buffer amplifiers 205 and 207 that are identical in amplification. The outputs of buffer amplifiers 205 and 207 are connected to a bridging circuit consisting of resistors 209 and 211 that are equal in value and are joined at

10   junction 223. The inputs of full wave rectifiers 213 and 217 are connected to the outputs of buffer amplifiers 205 and 207, respectively, and the input of full wave rectifier 215 is connected to junction 223. The instantaneous signal voltage at junction 223 will be equal to the average of the instantaneous signal voltage at junctions 227 and 229. Thus the output of full wave rectifier 213 will be a fluctuating positive voltage that will represent

15   the absolute value of the instantaneous signal of Channel 1 after processing through the low frequency attenuator 53 of Figure 1. Similarly, the output of full wave rectifier 217 will represent the absolute value of the instantaneous signal of Channel 2 after passing through the low frequency attenuator 55 of Figure 1. As resistors 209 and 211 are identical in value, full wave rectifier 215, which receives its input from junction 223 of

20   these two resistors, the output of full wave rectifier 215 will represent at any given moment the absolute value of the average of the instantaneous signal of Channels 1 and 2.

The output 233 of rectifier 215 is connected to the negative input terminal of both subtraction circuits 219 and 221 through junction 216. The positive input terminal of subtraction circuit 219 is connected to the output 231 of rectifier 213, which derives its signal from Channel 1, and the positive input terminal of subtraction circuit 221 is

5   connected to output 235 of rectifier 217, which derives its signal from Channel 2. The voltage differential between the input terminals of subtraction circuit 219 is expressed at output 249 and transmitted to the positive input terminal 237 of comparator 257. Similarly, the output 251 of subtraction circuit 221 is connected to the positive input terminal 243 of comparator 259. Voltage biasing devices 240 and 246 are connected to

10   negative terminals 239 and 245 of comparators 257 and 259, respectively. The subtraction circuits 219 and 221 subtract the instantaneous voltage of their negative input terminal from the instantaneous value of their positive terminal, the results being delivered to terminals 249 and 251, respectively, which are connected to the positive input terminals 237 and 243 of comparators 257 and 259, respectively. The threshold point of operation

15   of the comparators is chosen by means of a user-operated dual potentiometer that sets the same bias point at the negative input terminal of each, thus assuring an exact reciprocity of action in the noise reduction activities of each channel. The voltage at the circuit junctions (227, 229, 223, 231, 233, 235, 249, 251, 253 & 255) determine when the fast acting switches 27 and 29 (Figure 1) are opened or closed.

20   Operation of the control circuit of Figure 2 under each of these operating conditions will now be explained.

In Case 1 consider that signals substantially identical both in polarity and in amplitude are received simultaneously at Channel 1 and Channel 2. This case represents a momentary condition in which there is no appreciable noise component in either channel. Voltages at 227 and 229 are identical, or closely so, and the voltage at junction 223 is at

5 the average of those at 227 an 229. The full wave, positive, pulsating waveforms at junctions 231 and 235, i.e., the outputs of full wave rectifiers 213 and 215, respectively, nearly match in value and polarity such that the difference voltage at the output 249 of the subtraction circuit 219 is negligible in normal operation of the device and at a value less than the user-adjusted positive DC voltage connected to the inverting input 239 of

10 comparator 257. Thus, the output 253 of comparator 257 is insufficient to actuate the normally open fast acting switch 29 and terminals 59 and 63 (Figure 1) are not connected. Likewise, the positive, pulsating wave forms at 233 and 235 nearly match with the result that the difference voltage at 251 is negligible and at a value less than the pre-established positive voltage connected to the inverting input of comparator 259. The output 255 of

15 comparator 259 is too low to actuate the normally open fact acting switch 27. Thus, terminals 57 and 61 are not connected. Consequently, equal value resistors 101 and 102 conduct signals from low frequency attenuators 53 and 55 to summer 31, In this manner, when there is negligible noise and, thus, the instantaneous signals of Channel 1 and Channel 2 are identical, or almost so, the output of summer 31 provides a monaural mix of

20 the signals received at Channels 1 and 2.

In Case 2 consider that an instantaneous voltage is received at the input of Channel 1 and that a lesser input voltage of the same polarity is received at the input of Channel 2,

simultaneously applying a voltage, V, at 227 and a voltage, kV, at 229, where k is a

positive number between 0 and 1. The voltage resulting at 223 will be the average of the

two voltages, namely $(k+1)V/2$. The voltages at 227, 223 and 229, after undergoing full

wave rectification, will be expressed as positive voltages at 231, 233 and 235 that will

5   have values, respectively, of V^1, $(k+1)$ $V^1/2$ and V^1. The voltage at 249 is equal to the

voltage at 231 minus the voltage at 233 or $(1-k)$ $V^1/2$. Since k has a value between 0 and

1, the voltage at 249 is positive. Through the conditions posited for Case 2, the

magnitude of the positive voltage at 249 exceeds the magnitude of the positive, pre-

established, user-adjustable voltage at the inverting input of comparator 257. The output

10   at 253 is high, resulting in a connection between terminals 59 and 63 of the fast-acting

switch 29, as the resistance of closed fast-acting switch 29 is much smaller than that of

resistor 102. The voltage at 251 is the voltage at 235 minus the voltage at 233, or $(k-1)$

$V^1/2$. Since k is between 0 and 1, the voltage at 251 is negative. This negative voltage at

251 and the positive, pre-established voltage at the inverting input 245 of comparator 259

15   result in output 255 being low. Consequently, fast acting switch 27 remains in the open

position. Summer 31 accepts signals from Channel 1 through resistor 101 and from

Channel 2 through fast acting switch 29. Since the resistance of closed switch 29 is much

smaller than the resistance of resistor 101, and in consideration of the voltage divider

action between two resistances, the signal from Channel 1 is not conducted. In this

20   manner, when there is noise in Channel 1 and a lesser amplitude of the same polarity in

Channel 2, the output of summer 31 delivers only the signal received in Channel 2,

Through a similar consideration, should the greater instantaneous voltage of the same

polarity be received at Channel 2, the output of summer 31 will deliver only the signal

received at Channel 1.

In <u>Case 3</u>, consider than an instantaneous voltage is at Channel 1 and that an

instantaneous voltage of opposite polarity and lesser amplitude is received at Channel 2,

5   Channel 1 providing a voltage, V, at 227 and Channel 2 providing a voltage, -kV, at 229,

where k is a positive number between 0 and 1. The voltage at 223 will be (1-kV)/2, the

average of the voltages at 227 and 229. The voltages at 227, 223 and 229 are then full-

wave rectified by rectifiers 213, 215 and 217, respectively. Note, in particular, that

although the voltage at 229 which enters full wave rectifier 217 is negative, namely -kV,

10   the voltage at 235 will be the positive quantity represented by kV^1. The voltage at 249

will equal the voltage at 231 minus the voltage at 233, or $(1+k)V^1/2$. Through the

conditions posited for Case 3, and the magnitude of the positive voltage at 249 exceeds

the magnitude of the positive, pre-established voltage at the inverting input 239 of user-

adjusted comparator 257 in normal operation of the device. Consequently, fast acting

15   switch 29 will close, connecting terminals 59 and 63. The instantaneous signal at 251 is a

linear function of the voltage at 235 minus the voltage at 233, i.e. (3k-1)V/2. If k has a

positive value between 0 and 1/3, the polarity at 251 is negative, the output of comparator

259 is low and fast acting switch 27 will remain open, If k is a positive number between

1/3 and 1 and, through the conditions posited as Case 3, the magnitude of (3k-1) $V^1/2$

20   exceeds the positive, pre-established, user-adjusted voltage at the inverting input 245 of

comparator 259, then the output of comparator 259 assumes a value sufficient to close

fast acting switch 27. In this manner, when the magnitude of the instantaneous voltage of

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Channel 2 is between 1/3 of and equality with the instantaneous voltage of Channel 1, and

of opposite polarity, the circuit chooses an equal mixture (i.e. the average) of Channels 1

and 2. Through the foregoing process of analysis, it can be demonstrated that if the

magnitude of the instantaneous voltage of Channel 1 is between 1/3 of and equality with

5   the instantaneous voltage of Channel 2 and of opposite polarity the output of the circuit is

also an equal mixture (i.e. the average) of Channels 1 and 2.

Figure 3 illustrates another control circuit that can be used in place of the preferred

circuit just described. Input buffers 301 and 302 of the Figure 3 embodiment serve the

same functions and circuit positions as do buffers 205 and 207, respectively, of Figure 2,

10   and the outputs of OR gates 311 and 312 operate switches 27 and 29, respectively, of

Figure 1 in the same manner as comparators 257 and 259 of the control circuit of Figure

2. Full wave rectifiers 305 and 306 track the absolute magnitude of the instantaneous

peak value of the input signal (i.e. program plus noise) of input Channels 1 and 2

respectively. The output of rectifier 305 is connected to the positive input terminal of

15   subtraction circuit 308 and the output of rectifier 306 is connected to the negative input

terminal of subtraction circuit 308. The output of subtraction circuit 308 connects to both

the positive input terminal of comparator 309 and the negative input terminal of

comparator 310. The negative input terminal of comparator 309 receives a positive D.C.

bias from a user-adjustable voltage source 313 and the positive input terminal receives a

20   negative D.C. bias from a user-adjustable voltage source 315. The user-adjustment is

accomplished by means of two concentrically mounted linear taper potentiometers

identical in value, so as to provide bias voltages at comparators 309 and 310 equal in

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value though opposite in polarity. The output of comparator 309 connects to one input of OR gate 311 and the output of comparator 310 connects to an input of OR gate 312.

The output of subtraction circuit 308 is positive when the instantaneous absolute voltage of Channel 1, as transmitted by buffer 301 and full wave rectifier 305, exceeds in magnitude the instantaneous absolute voltage of Channel 2, as transmitted by input buffer 302 and full wave rectifier 306. If the positive output from the subtraction circuit 308 exceeds the pre-established positive voltage at the inverting input of comparator 309, comparator 309's output is a positive voltage. As a result, the output of OR gate 311 is assured of being a positive voltage irrespective of the polarity of its other input, thus causing fast-acting switch 29 to close. Thus this signal from Channel 2 is received by summer 31 while signal from Channel 1 is excluded. Conversely, the output of subtraction circuit 308 is negative if the instantaneous absolute value of the input signal (i.e. program plus noise) voltage of Channel 2 exceeds in magnitude the instantaneous absolute value of the input signal voltage of Channel 1. If the negative output voltage from subtraction circuit 308 exceeds the pre-established negative voltage at the non-inverting input of comparator 310, the output of comparator 310 assumes a positive value. The output of OR gate 312 goes high irrespective of the voltage state of its other input and fast acting switch 27 is closed. This results in signal from Channel 1 being received by summer 31 (Figure 1) at the exclusion of signal from Channel 2. In this manner, when there is noise in Channel 2 and a lesser noise in Channel 1, the output of summer 31 is only the signal from Channel 1. The positive inputs of comparators 303 and 304 are connected to the outputs of buffers 301 and 302, respectively. The negative inputs of comparators 303 and 304 are

connected to ground. The output of comparator 303 goes positive when the voltage from buffer 301 is positive with respect to ground. The output of comparator 304 goes positive when the voltage from buffer 302 is positive with respect to ground. The outputs of comparators 303 and 304 are connected to the two inputs of EXCLUSIVE OR gate 307.

5   The output of EXCLUSIVE OR gate 307 goes positive if the output of comparator 303 alone or 304 alone is positive. Expressed differently, EXCLUSIVE OR gate 307 is negative if the signals on Channels 1 and 2 are of the same polarity, and the output of EXCLUSIVE OR gate 307 is positive if the signals on Channels 1 and 2 are of opposite polarity. The output of EXCLUSIVE OR gate 307 is connected to the other inputs of OR

10   gates 311 and 312. If the output of EXCLUSIVE OR gate 307 is positive, the outputs of OR gates 311 and 312 are positive irrespective of the voltage applied at their other inputs. Fast acting switches 27 and 29 both close, imparting a monaural mix of signals from Channels 1 and 2 to summer 31. As has been described, the alternate embodiment represented in Figure 3 produces the same actions as the embodiment in Figure 2, except

15   in the case of input signals in Channels 1 and 2 having opposite polarity. The Figure 2 embodiment enables a monaural mix of the input signals when the input signals are of opposite polarity and have amplitudes within 30% of each other. Whereas the embodiment of Figure 3 enables a monaural mix of the two signals if the signals are of opposite polarity at all relative levels to each other.

20   In some situations where it is not necessary or desirable to suppress "ticks" or other transient noise components, there may exist dropout, fading or other sudden changes in the level of the input signal which it may be desired to alleviate. The latter object can be

achieved with the circuit in Figure 2, modified by connecting the input of rectifier 213 to

junction 229 (the output of amplifier 207) thereby deriving signal from Channel 2, and

connecting the input of rectifier 217 to junction 227 (the output of amplifier 205) thereby

deriving signal from Channel 1. Outputs from subtraction circuits 219 and 221 and

5   comparators 257 and 259 are now reversed and the operations of fast-acting switches 27

and 29 are also reversed. Thus, the fast-acting switches 27 and 29 that normally function

to assure the transmission of signal from the channel that has the lesser total instantaneous

signal level with respect to the average signal of the two channels will now function to

secure transmission of the signal from the channel that has the greater instantaneous total

10   input signal level. By replacing the permanent connections shown in Figure 2 between the

input of rectifier 213 and junction 227 and the permanent connection between the input of

rectifier 217 and junction 229 with a reversing switch, one can achieve, with one piece of

equipment, the two modes of operation. Such a switch is also useful in demonstrating and

testing the operation of the Switcher by comparing the noise audible in the two different

15   positions of the switch. This feature is disclosed in earlier referenced Patent No.

4,259,742.

<div align="center">The Blanker</div>

After processing by the Switcher the signal next enters the Blanker, a preferred

embodiment of which is shown in Figure 4.

20   This processor limits the amplitude of noise transients by dividing the signal

channel into a high frequency path and low frequency path wherein high frequency noise

transients are limited in accordance with the peak amplitude of the program component in

the vicinity of each individual noise transient and noise transients in the low frequency path are discriminated from program transients by virtue of the noise transients' high frequency content and limited in accordance with the peak amplitude of the low frequency path's program content in its vicinity. The two paths are then re-united such that the signal

5   exiting the Blanker is identical with the input signal save for the suppression of the noise transients.

The incoming signal is applied simultaneously to the input of high pass filter 405 and to low pass filter 407, thus dividing the signal into two branches, in one of which the low frequency transient noises are to be eliminated or suppressed and in the other of which

10   the high frequency transient noises are to be eliminated or suppressed. High pass filter 405 has a low frequency attenuation characteristic of 12 db per octave with its turnover frequency at 800 Hz and low pass filter 407 has a characteristic inversely complementary to that of 405 starting, also, at 800 Hz , such that signal paths 430 and 432, when re-combined in mixer 427, will become a signal identical to the input signal with the

15   exception that noise transients have been eliminated or suppressed.

The elimination of transient noises is effected by switch 401 for the high frequency signal path and by switch 403 for the low frequency signal path. Both switch 401 and switch 403 are fast-acting, normally closed switches. Each switch opens whenever its control circuit detects a noise transient that is to be eliminated. The charge on either

20   capacitor 423, connected to the output terminal 402 of switch 401 to ground, or on capacitor 425, connected to the output terminal 404 of switch 403 to ground, serves to provide a signal continuity in its path during the brief time that the switch is open.

Switch 401 is triggered to open by comparator 424 when the voltage at the

negative input terminal 463 of comparator 401, which is derived from the total signal

(program plus noise) at the output of high pass filter 405, exceeds the voltage at positive

input terminal 426 of comparator 401, which voltage is indicative of the "signal without

5   noise" level from high pass filter 405, as follows: The output of high pass filter 405, the

characteristics of which were described above, has a connection to the low pass filter and

time delay unit 404. Filter 404 has an 18db per octave high frequency attenuation

characteristic with its turnover frequency at 3 kHz. Since the signal entering filter 404 had

previously undergone an attenuation of low frequencies of 12 db per octave starting at

10   800 Hz, the signal emerging from filter 404 has had its components below 800 Hz and

above 3 kHz drastically diminished in magnitude. The frequency range below 3 kHz is the

range in which the program content of the input signal dominates over high frequency

surface noise of recordings such that the output of filter 404 can successfully be taken as

representative of the level of signal without high frequency noise. In addition it is not

15   desirable that transients or program material below 800 Hz influence the operation of

switch 401. The output of filter 404 is connected to the input of full wave rectifier 406

the output of which is connected to junction 408. Thus, junction 408 registers the

momentary absolute value of signal from filter 404. Resistor 410 is connected between

the output of full wave rectifier 406 and the input of rectifier 416. Rectifier 406 in

20   conjunction with capacitor 415 and potentiometer 420, both connected to ground, serves

as a peak detector. Should the voltage at rectifier 416 diminish, the voltage on capacitor

415 discharges through the resistance of potentiometer 420, the discharging time constant

chosen to be approximately 100 milliseconds. The slider of potentiometer 420 is

connected to the input of D.C. amplifier 422, the output of which is connected to the

positive input terminal 426 of comparator 424. Thus, the relatively slowly discharging

voltage at the output of peak detector (rectifier) 416 is providing, by means of user-

5   adjustable potentiometer 420 and D.C. buffer amplifier 422, threshold voltage at positive

terminal 426 of comparator 424, this threshold voltage being representative of the ever-

changing absolute value of the program content (signal-without-noise) of the signal. The

output of high pass filter 405, expressing high-frequency components of the input signal, is

connected to full wave rectifier 409, which has no capacitor associated with it to slow its

10 charging or discharging time, thus constituting a tick detector. The output of rectifier 409

is connected directly to negative terminal 463 of comparator 424. When a tick whose

frequency content exceeds 3 kHz occurs and the positive voltage at input 463 exceeds the

positive voltage of input 426 of comparator 424 thereby, the output of comparator 424

becomes sufficiently negative to open switch 401. Thus, the ticks exceeding

15 approximately 3 kHz are not transmitted from high pass filter 405 to mixer 427 when the

tick amplitude exceeds the threshold voltage at terminal 426, which is governed by the

sum of the voltage output of peak detector 416 and, futhermore, by the setting of user-

adjustable potentiometer 420. Low frequency noise transients are typically caused by

scratches, needle drops and cracks in the record. Playback of these yields loud noise

20 transients, rich in both low and high frequencies. Music instruments that produce strong

low frequency transients, most notably drums, are far less rich in high frequency transients

than are the scratches, needle drops and cracks. Thus, we are provided with a useful

criterion for distinguishing between loud, low frequency noise transients and low frequency music transients.

Low frequency noise transients are suppressed by opening fast acting switch 403. Switch 403 is controlled by NAND gate 421 and opens if the output of NAND gate 421 is sufficiently negative, which requires that positive voltages be applied simultaneously to terminals 434 and 436 of NAND gate 421. Input terminal 434 is connected to the output of comparator 419 which is a positive voltage when the positive instantaneous voltage at the output of full wave rectifier 411 connected to the positive input terminal of comparator 419 exceeds the positive voltage at the negative input terminal of comparator 419. The positive input terminal of comparator 419 is connected to the output of full wave rectifier 411, the input of which is connnected to the output of low pass filter 407. The negative input of comparator 419 is connected to the output of a peak detector consisting of rectifier 417 and resistor 457 feeding capacitor 451 and resistor 453, the latter both connected to ground. The purpose of resistor 457 is to provide a time delay of approximately five milliseconds in the charging of capacitor 451 so that the voltage at the output of peak detector, junction 459 is not affected by short noise transients. The input of full wave rectifier 411 is connected to the output of low pass filter 407 and the input of rectifier 417 is connected to the output 435 of full wave rectifier 409. The input of full wave rectifier 409 is connected to the output of high pass filter 405. The values of capacitor 451 and resistor 453 are chosen to provide a discharging time constant of approximately 20 milliseconds. The discharging time constant provides some short term stability to the voltage serving as bias voltage to the negative input terminals of

comparators 419 and 441. The positive input terminal of comparator 441 is connected to the junction of resistors 428 and 429. The other end of resistor 428 is connected to ground and the other end of resistor 429 connects to junction 435 the output terminal of full wave rectifier 409 Resistors 428 and 429 attenuate the voltage derived from junction

5   435 in order that switch 403 opens only in response to large amplitude, high frequency noise transients, i.e., those that exceed the peak program content by a factor of three or more, as lesser noise transients do not typically have enough low frequency content to warrant a blanking procedure in the low frequency signal path. If the transient at the positive input terminal of comparator 441 received from rectifier 409 and high pass filter

10   405 exceeds the peak signal at 459, its negative input terminal, the output of comparator 441 becomes sufficient to trigger monostable multivibrator 443. The output voltage of multivibrator 443 closes fast acting switch 414 for approximately 1.5 milliseconds. When fast acting switch 414 is closed, the signal at the ouput of resistor 410 is shorted to ground.

15   Filter 404 is intended to feed "music" signal through rectifier 406 through peak detector 416, buffer amplifier 422 and to the input 426 of comparator 424. The 3 kHz corner frequency selected for filter 404 is suitable for eliminating high frequency ticks but may pass some low frequency tick transients. Due to the delay in filter 404, control switch 414 will be triggered to close before the low frequency transient appears at the output of

20   filter 404. During the 1.5 milliseconds that switch 414 is closed, the 100 millisecond time constant of the circuit at the output of peak detector 416 serves to maintain the voltage that it had just before switch 414 closed, so that the circuitry that operates switch 401 will

be undisturbed by low frequency noise transients having frequency components below 3

kHz. The output of monostable multivibrator 443 also connects to the second input 436

of NAND gate 421. When there is a tick having sufficient amplitudes determined both

above and below 3 kHz, there is sufficient positive voltage at inputs 434 and 436 to make

5   the output at NAND gate 421 sufficiently negative to open switch 403. In this manner the

low frequency ticks at low pass filter 407 are not transmitted to mixer 427. If desired,

visual indicators of operability of either of both of switches 401 and 403 may be provided.

For example, light emitting diode 461 is connected to the output of comparator 424 and,

through series resistor 462, to ground without compromising the output voltage of the

10   comparator driver. When the output of the comparator goes low, light emitting diode 461

illuminates to indicate opening of switch 401.

The Continuous Noise Suppressor

The input of the system shown in Figure 5 is connected to buffer amplifier 501.

The output of the buffer amplifier connects to the input of voltage controlled filter 502,

15   the output of which connects to the input of voltage controlled filter 503, the output of

which connects to the input of amplifier 504, which is the output amplifier of the

Continuous Noise Suppressor system. Each of the voltage controlled filters has a high

frequency attenuation characteristic of 6 db per octave with the turnover frequency being

directly proportional to a control voltage applied simultaneously at terminals 507 and 508,

20   respectively, of the filters 502 and 503 by the control unit, the components and

configuration of which are diagrammed below the dashed lines in Figure 5. Voltage

controlled filter 503 is designed so that its cutoff frequency is approximately an octave

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above the cutoff frequency of filter 502 for all values of the control voltage applied to each simultaneously, thus producing at the output of filter 503 a response curve that will be at an attenuation rate of 6db per octave for the first octave of attenuation and at a rate of 12 db per octave starting at the second octave of attenuation. This attenuation curve

5 was determined to be more subtle and effective in listening tests than is the previously employed curve of 8 db per octave with no inflexion point that was employed in the unit described in U.S. Patent No. 4,322,641.

The comparison and control means, which are diagrammed below the dashed lines in Figure 5, has two branches. The upper branch, which is representative of the "music"

10 content of the signal, receives its input from the output of input buffer amplifier 501. The signal in this branch is processed through band pass filter 505, with corner frequencies of approximately 1 kHz and 3 kHz. The output of the band pass filter 505 connects to the input of a peak detector which consists of full wave rectifier 507, resistor 509 and capacitor 517. Resistor 509 connects the output of rectifier 507 to the input 524 of

15 voltage divider integrated circuit 525 and also to capacitor 517 and resistor 519, the other side of each of the latter two being grounded. The full wave rectified voltage appearing at terminal 524 is taken as representative of the program component of the total signal.

In the lower branch of the control circuit the signal passes successively through two differentiators 511 and 513 in series. The output of differentiator 513 is connected to

20 a peak detector consisting of full wave rectifier 515, resistor 516 and capacitor 521. Resistor 516 connects the output of rectifier 515 to input 526 of voltage divider integrated circuit 525 and also to capacitor 521 and resistor 523, the other side of each of the latter

two being grounded. The signal at 526 is representative of the rate of change of the rate

of change (i.e. of the acceleration component) of the input signal. Values of capacitor 517

and resistor 519 are chosen to provide a time constant of approximately five milliseconds,

thus producing some short term stability of the signal at 524 and also playing a role in

5   desensitizing the unit from being disturbed by noise transients, as the value of resistor 509

is chosen to provide, in combination with capacitor 517, a time constant of approximately

2 milliseconds. Similarly, in the lower branch, capacitor 521 and resistor 523 have a time

constant of about 2.5 milliseconds and capacitor 521 and resistor 516 are chosen to

produce a time contant of approximately 1 millisecond. Noise transient de-sensitization is

10   needed when this processor is employed as a stand-alone device. However, noise

transient de-sensitization is accomplished by the addition of only two resistors (509 and

516) and is also beneficial should an unexpected noise transient succeed, at least in part, in

getting through the two previous processors. The output voltage divider integrated circuit

525 provides a voltage that is proportional to the ratio of the voltage at terminal 524 to

15   that at terminal 526. Resistor 527 is connected between the output of integrated circuit

525 and the high end of potentiometer 529. The slider of potentiometer 529 goes to input

532 of mixer 531 and the other end of potentiometer 529 goes to ground. Potentiometer

529 is user-adjustable and is labeled "Ceiling". The other input terminal 534 of mixer 531

is connected to a D.C. bias arrangement symbolized by a D.C. voltage source 535 with a

20   potentiometer 533 in series with resistor 537 connected across it. This potentiometer is

also user-adjusted and is labeled "Floor". The slider of potentiometer 533 provides a

user-adjusted means of applying a steady-state voltage to the input 534 of mixer 531.

Consequently, the voltage at the output terminal of mixer 531 will be representative of the sum of the fluctuating voltage output of ratio detector 525 and the user-adjusted bias voltage. The voltage at the output at mixer 531 is applied to the control inputs of both filters 502 and 503. The output of mixer 531 is also connected to the input of meter 539, which is provided with a scale calibrated to read the cutoff frequency of filter 502 as a function of the voltage at the output of mixer 531.

Thus, the momentary cutoff frequency is determined by the sum of the steady bias voltage, user-adjusted by the slider of potentiometer 533, and by the varying voltage from circuit 525, the effect of which is regulated by the user-adjustable slider of potentiometer 529; the higher the sum of the two voltages, the higher the cutoff frequency. When no signal is applied to the input of buffer amplifier 501 the cutoff frequency reading of meter 539 and the configuration of the low pass filters 502 and 503 will be a steady value dependent on the slider setting of potentiometer 533. Then, when one starts to play a record, the meter needle will immediately become active as the voltage at the slider of potentiometer 529 is added to that from the slider of potentiometer 533 in the mixer 531. When the music component of the total signal is strongest the ratio of the voltage at input 524 to that at 526 will be at its highest value. By adjustment of the slider of potentiometer 529, the user selects the fraction of the voltage that will enter 532 to add to the D.C. voltage from the slider of potentiometer 533 and, consequently, raise the cutoff frequencies of filters 502 and 503. This voltage is also applied to the meter 539 which now will be reading the instantaneous values of the varying output voltage of mixer 531, which the meter shall indicate as cutoff frequency. Meter 539 is an important aid to the

user, adding the faculty of vision as a valuable supplement to the sometimes difficult-to-judge auditory perceptions of the Continuous Noise Suppressor output.

Summary

The invention described herein thus effectively reduces noises in sound signals in a

5   manner which is not audibly discernible and does not impair the quality of the sound

signal. The circuit of the preferred embodiment is both practical and economical and is

effective in use.

In the Switcher of the prior art, the magnitudes of the two channels were

compared and if they differed by a sufficient amount indicative of transient noise

10   components, the channel having the lesser magnitude was transmitted to the output of the

Switcher. In this manner only one channel or the other was enabled through the closure of

the channel's fast acting switch, or, in cases of noise below a threshold value in both

channels, both switches remained open. While the prior art device was effective for the

reduction of noise occurring as momentary and separated events between the two channels

15   it failed to address the added possibility of noise occurring simultaneously in the two

channels. In particular, during the instances of simultaneous noise there is the possibility

of the noise components being of opposite polarity but of non-matching amplitude such

that the best approximation of the music component is the average of the total signals of

the two channels. The present invention is able to address such instances by enabling both

20   channels to be conducted to the output of the switcher through simultaneous closure of

the two fast acting switches, one switch located in each channel. This and other aspects of

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the present invention furthermore allow a more sensitive and effective threshold of operation.

The noise transient was recognized by the prior art Blanker as total signal having greater amplitude than in a preceding, pre-established interval of the total signal. A fast acting switch responded to detected noise transients, serving to interrupt transmission of the noise transients to the output of the blanker. However, the device would sometimes remove the leading edges of desired music transients, particularly music transients having low frequency components such as drum beats, voice and piano. This problem has been remedied in the present invention by utilizing two fast acting switches. The first switch is designed to interrupt only the high frequency components of the noise transient and thereby mitigate the possibility of its distorting low frequency music. The second switch is designed to interrupt only the low frequency components of the noise transient. In another aspect of the invention, the second fast acting switch is enabled only when sufficient levels of high frequency signal is detected, thereby opening upon the occurrences of deep scratches in the recording medium and, in general, during noise events typically having high frequency spectra, but prevented from opening upon the occurrences of music transients of low frequency.

In the prior art continuous noise, otherwise known as white noise or hiss, was separated from the total input signal through differentiation. The total input signal was also processed through a band pass filter such that the output represented a pre-selected frequency portion of the music content within the total input signal. The magnitures of the noise content and music content thus derived were compared to form a control signal

which governed the cutoff frequency of a low pass filter. The low pass filter served to limit the amount of high frequencies in the total input signal transmitted to the output of the Continuous Noise Suppressor. While the device removed continuous noise in varying relationship with the music program, the activity of the control signal was inadequate for

5   total input signals having appreciable continuous noise, in which case the differentiated signal representing noise overwhelmed the signal derived from the band pass filter representing music. In the present invention the control signal is a ratio of the band pass filter and the differentiated signal, resulting in the variations of the control signal even when excessive continuous noise is present. Another advantage of ratioing compared to

10   the prior art is the ability to determine the control signal more quickly and with fewer components. The improved responsiveness of the control signal to the music component of the total signal facilitates the removal of continuous noise without the disturbance of the high frequency music components contained in the total input signal.

The invention has been described in detail with particular emphasis on the

15   preferred embodiment, but it will be understood that variations and modifications within the spirit of the invention may occur to those skilled in the art to which the invention pertains.